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SWIR AIR GLOW MAPPING OF THE NIGHT SKY: POSTPRINT

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14. ABSTRACT IT IS WELL KNOW THAT LUMINANCE FROM PHOTO-CHEMICAL REACTIONS OF HYDROXYL IONS IN THE UPPER ATMOSPHERE (-85 KM ALTITUDE) PRODUCES A SIGNIFICANT AMOUNT OF NIGHT TIME RADIATION IN THE SHORT WAVE INFA-RED (SWIR) BAND BETWEEN 0.9 AND 1.7 UM WAVE LENGTH. NUMEROUS STUDIES OF THESE PHENOMENA HAVE DEMONSTRATED THAT THE IRRADIANCE SOWS SIGNIFICANT REMPORAL AND SPATIAL VARATIONS. CHANGES IN WEATHER PATTERNS, SEASONS, SUN ANGLE, MOONLIGT, ETC. HAVE THE PROPENSITY TO ALTER THE AWIR AIR GLOW IRRADIANCE PATTERN. BY PERFORMING MULTIPLE SWIR MEASUREMENTS A MOSAIC REPRESENTATION OF THE CELESTIAL HEMISPHERE CAN BE CONSTRUCTED AND USED TO INVESTIGATE THE VARATIONS OVER TIME AND SPACE. THE EXPERIMENTAL SETUP CONSISTS OF TWO SENSORS, ONE A INGAAS SWIR DETECTOR AND THE OTHER A VISIBLE ASTRONOMICAL CAMERA, CO-LOCATED AND BORE SIGHTED ON AN AZ-EL GIMBAL. THE GIMBAL IS PROGRAMMED TO VIEW 45 DESCRETE AZIMUTH AND ELEVATION LOCATIONS WHICH COVER THE ENTIRE SKY. THE DWELL TIME AT EACH LOCATION IS 30 SECONDS WITH A TOTAL CYCLE TIME OF 30 MINUTES.

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SWIR Air Glow Mapping of the Night Sky

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Abstract

It is well known that luminance from photo-chemical reactions of hydroxyl ions in the upper atmosphere (~85 km altitude) produces a significant amount of night time radiation in the short wave infra-red (SWIR) band between 0.9 and 1.7 μm wave length. Numerous studies of these phenomena have demonstrated that the irradiance shows significant temporal and spatial variations. Changes in weather patterns, seasons, sun angle, moonlight, etc have the propensity to alter the SWIR air glow irradiance pattern. By performing multiple SWIR measurements a mosaic representation of the celestial hemisphere can be constructed and used to investigate the variations over time and space. The experimental setup consists of two sensors, one a InGaAs SWIR detector and the other a visible astronomical camera, co-located and bore sighted on an AZ-EL gimbal. This gimbal is programmed to view 45descrete azimuth and elevation locations which cover the entire sky. The dwell time at each location is 30 seconds with a total cycle time of 30 minutes. The visible astronomical camera collects image data simultaneous with the SWIR. The contrast between the two simultaneous images can be used for cloud detection. Data is reduced through batch processing to produces polar representations of the sky radiance as a function of azimuth, elevation and time. The resulting spatio-temporal variations in the radiance are used in conjunction with physical models of atmospheric chemistry and turbulence. The short term variations over a night as well as the long term variation over a season can be used to validate and calibrate these models. In this paper we present results of our measurements made over a several month period both in the semi-urban desert near Albuquerque New Mexico, and in a rural marine environment on the Islands of Kauai and Maui Hawaii.

1.0 INTRODUCTION

Sky glow from chemical luminescence in the upper atmosphere has been observed at a number of different wavelengths [1-3]. In the short wave infra-red (SWIR) between 1.0 μm and 1.7 μm, it is due to emissions from hydroxyl radicals transitioning from excited rotational and translational states to lower energy states and emitting a SWIR photon in the process.

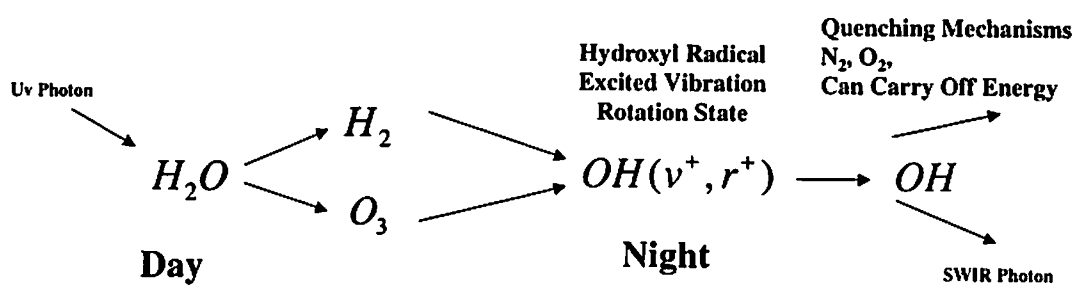


Figure 1.1 Synoptic Sketch of the Air Glow Process in the Infra-Red.

Figure 1.1 is a synoptic sketch of the air glow process for production of illumination in the SWIR band. Although the chemical reactions are very complicated, the overall effects can be summarized as follows. During the day, UV photons strike water molecules and initiate the production of hydrogen and ozone. At night, the hydrogen and ozone recombine and form the excited hydroxyl radicals with elevated vibration and rotational energy states. The molecules then transition to a lower energy state emitting a SWIR photon. The process can be quenched by other molecules, among them O_2 and N_2, which carry off the energy.

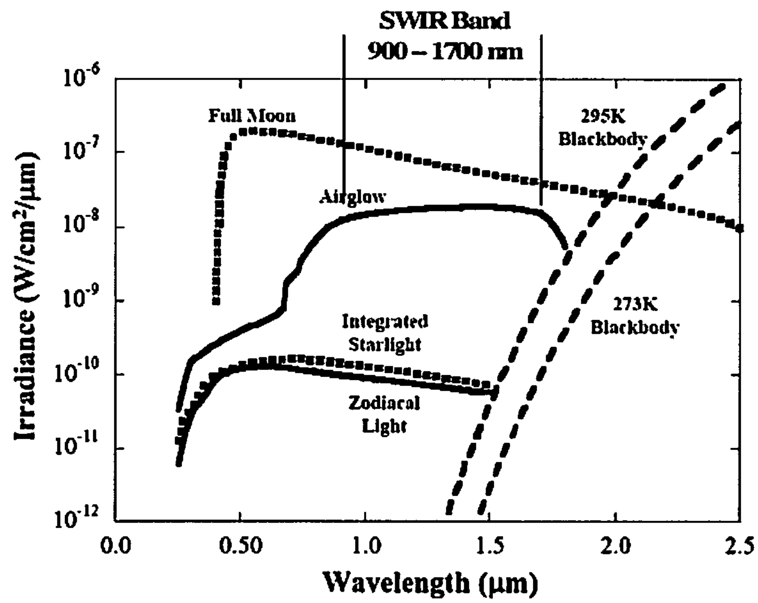


Figure 1.2 Night Time Illumination Sources

Figure 1.2 shows sources of night time illumination that can be used for imaging [1]. Of course the brightest source is the moon. When the moon is not out, or is obscured by clouds, figure 1.2 shows that sky glow provides a significant source much greater than thermal radiation in the SWIR band.

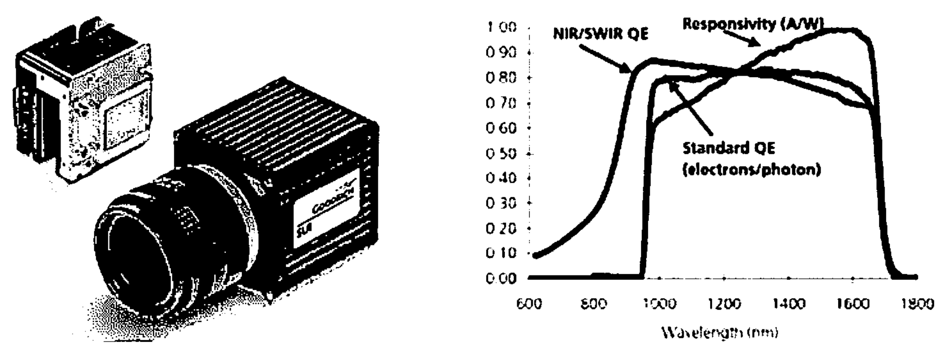


Figure 1.3 Sensors Unlimited SWIR Camera Used to Make SWIR Measurements of Sky Glow.

The SWIR camera used for the measurements was a Sensors Unlimited model 320KTX with 320x240x40 μm pixels. The camera has quantum efficiency above 60 % from 900 nm to 1700 nm as shown in the curve in figure 1.3. The effective read noise of the camera was about 50 equivalent detected photons per pixel.

SWIR image measurements shown in the subsequent sections were made using an F/1.4 50 mm focal length camera lens. With SWIR air glow irradiance levels, optics faster than F/2.5 are typically required for passive night glow imaging in order to concentrate enough light onto the detector array.

In order to make comparisons, two visible cameras were used in conjunction with the SWIR, an intensified CCD camera operated at 30 Hz, and a low noise CCD camera with 1 second exposures.

2.0 MEASUREMENTS

Image measurements were carried out at two sites, a simi-uban site about 10 miles south of Albuquerque, NM and a rural site on the west coast of the Hawaiian island of Kauai. At the Albuquerque site there is a considerable amount of ambient light from the city scattering off the bottoms of clouds. The Kauai site has very little ambient illumination other than direct and scattered moonlight. When the image measurement data was collected, the SWIR camera was mounted side by side with one of the visible cameras.

2.1 ALBUQUERQUE SITE

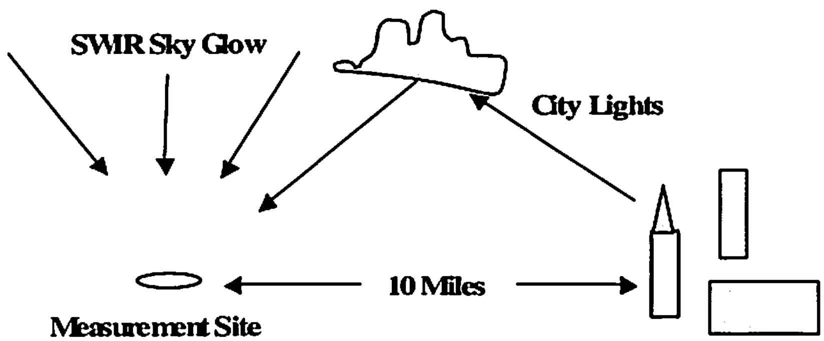
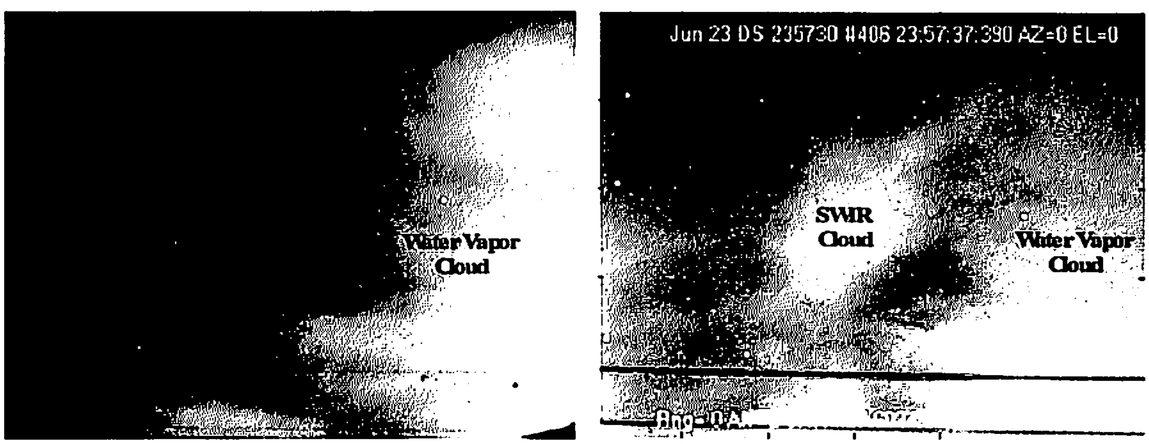


Figure 2.1 Albuquerque Semi-Urban Measurement Site

Figure 2.1 illustrates the illumination geometry of the Albuquerque test site. The measurement site was located about 10 miles south of town. We receive sky illumination directly from regions of the sky that are not blocked by clouds. We also receive indirect illumination from city light scattered off cloud bottoms.



Visible Camera SWIR Camera

Figure 2.2 Comparison of Visible and SWIR images from Albuquerque Site, -50 Deg from Zenith.

Figure 2.2 illustrates the comparison between visible and SWIR band images. In the visible band we see a water vapor cloud which scatters ambient city light. In the SWIR band we see the same water vapor cloud, but in addition we can see regions of sky glow that don't show up in the visible image.

Zenith Angle	SWIR SKY Glow Radiance Albuquerque Test Site
-80	2.9×10^{-8} W/cm2
-50	2.1×10^{-8} W/cm2
-10	4.2×10^{-9} W/cm2
0	3.5×10^{-9} W/cm2

Table 1 Sky Glow Irradiance Measurements as a Function of Zenith Angle Albuquerque Site.

The sky glow occurs in a layer of the atmosphere about 80 km above the ground. Simple geometric arguments can be used to show that as one looks closer to the horizon, the line of sight traverses a longer path through the sky glow gases. This means that one expects the sky glow irradiance to be greater from observations looking near the horizon as from observations looking near zenith. Table 1 shows the measured sky glow irradiance as a function of zenith angle. This table shows almost an order of magnitude difference in irradiance between observations made near the horizon on those made near zenith.

2.2 KAUAI SITE

We next consider the Kauai measurement site. This site is located on the west coast of the island with very little in the way of ambient street or housing light pollution. When the moon is not out, the only source of illumination is from the sky glow. The measurement site is near the edge of the ocean. Under the right conditions, it appears that we can observe sky glow reflection off the sea surface. Figure 2.3 illustrates this situation.

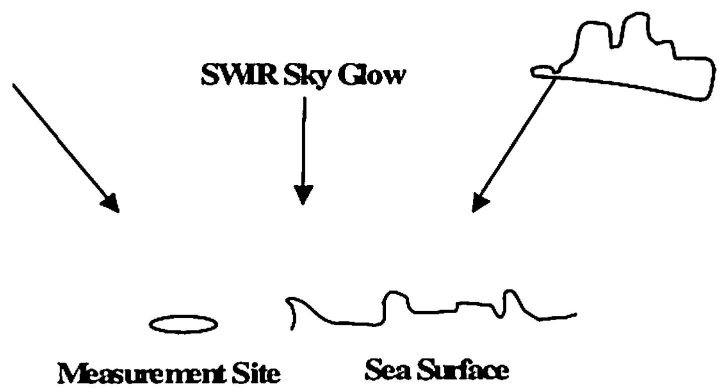
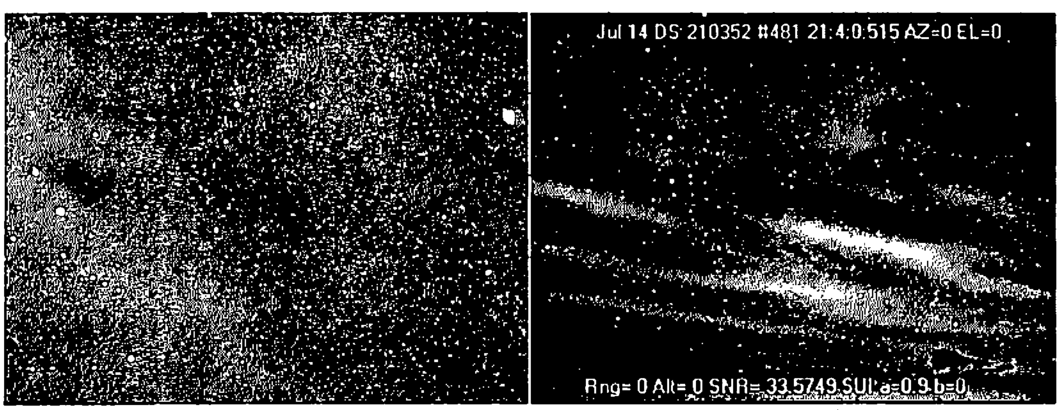


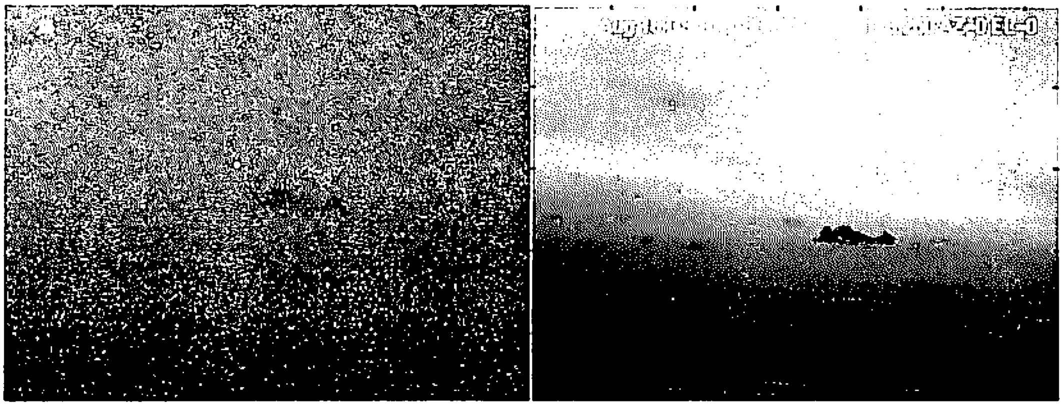
Figure 2.3 Kauai Rural Measurement Site



Visible Camera SWIR Camera

Figure 2.4 Comparison of Visible and SWIR images from Kauai Site.

Figure 2.4 shows some interesting intense striations and wave patterns in the sky glow radiance from the Kauai site. The irradiance from these striations was about 4.1×10^{-8} Watts per cm^2.



Visible Camera SWIR Camera

Figure 2.5 Sky Glow Measurements Near the Horizon.

Figure 2.5 shows sky glow measurements made near the horizon with the island of Niihau in the background. It can be seen from the visible camera data that there is very little ambient illumination.

The syk glow camera has been mounted to an AZ,EL gimbal in order to obtain scans of the full sky hemi-sphere in an automated fashion. The gimbal moves to a series of positions arranged in an annular pattern. At each position 30 seconds of image data are collected. The scan pattern is illustrated in figure 2.6.

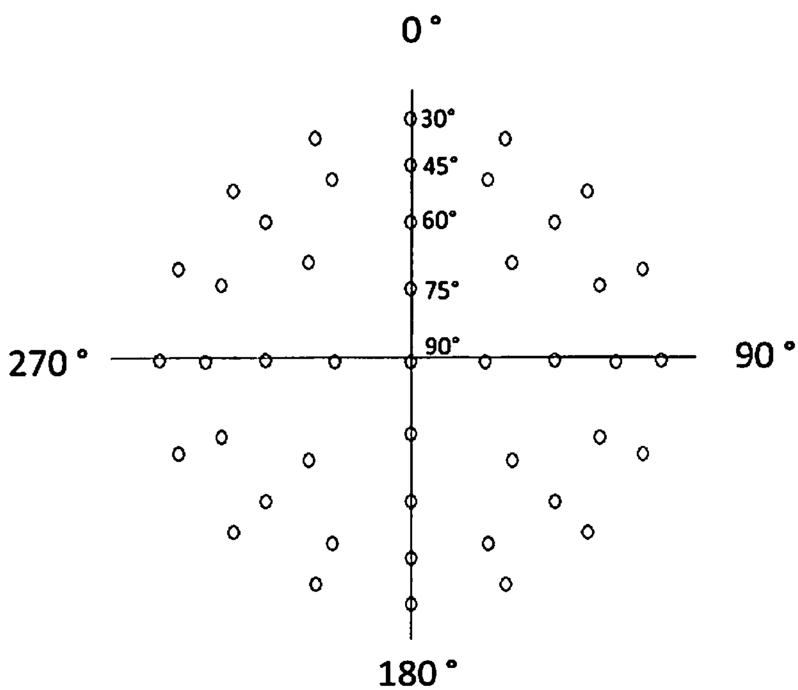


Figure 2.6 Annular Scan Pattern for Recording Sky Glow from the Full Sky

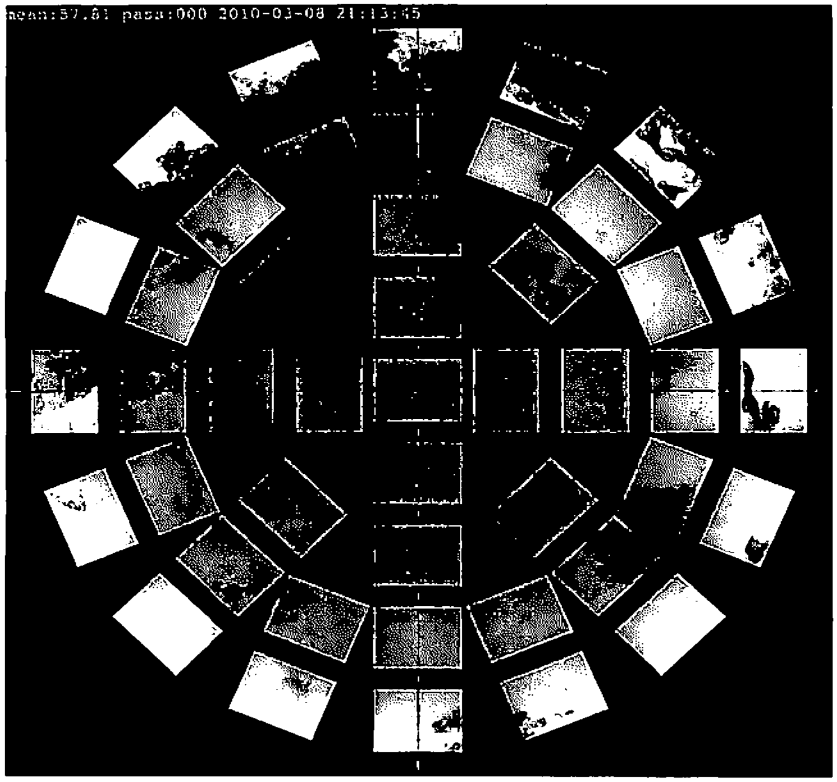
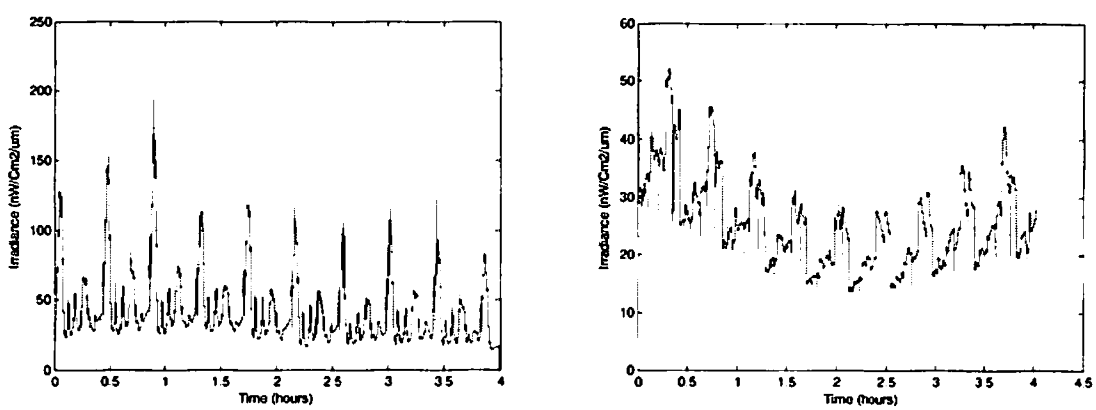


Figure 2.7 Annular Scan Pattern for Recording Sky Glow from the Full Sky

Figure 2.7 shows image frames that were collected at each of the scan positions shown in figure 2.6. The dark regions in the images are water clouds. The image frames are arranged in the same annular pattern as the scan pattern. Although all the image frames are not collected at exactly the same time, this collage presents a look at the sky glow hemisphere. It can be seen from the collage that the images taken near the horizon, on the outer ring, are brighter than those in the center. This is due to the fact that the sky glow intensity varies approximately as the cosine of the elevation angel from the horizon.



a) Intensity Pattern Showing Little Long Term Variation b) Intensity Pattern Showing Large Long Term Variation

Figure 2.8 Annular Scan Pattern for Recording Sky Glow from the Full Sky

Next figure 2.8 shows time series plots for sky glow data taken on two different nights in Kauai. Each point on the plot represents an average of the sky glow intensity over an image frame. As the gimbal moves through it annular scan pattern, we can see periodic fluctuations in the plots. This is due to variations of the intensity with elevation angle. The peaks in the time series occur when the gimbal is pointed near the horizon, and the minima when the gimbal is pointed near zenith. Comparing figures 2.8 a) and 2.8 b) we can see long term fluctuations in the intensity as well. This is particularly noticeable in figure b) where we see dip in the long term intensity at about the 2 hour point.

We can also measure the long term mean of the irradiance as a function of zenith angle. This is shown in table 2. The values in this table compare favorably with published measurements as shown in Figure 1.2.

Zenith Angle	**SWIR SKY Glow Irradiance Kauai**
-85	**3.9×10^{-8} W/cm^2**
-80	**2.3×10^{-8} W/cm^2**
-75	**2.5×10^{-8} W/cm^2**
-65	**1.3×10^{-8} W/cm^2**
-35	**4.6×10^{-9} W/cm^2**
-20	**4.5×10^{-9} W/cm^2**
0	**8.0×10^{-9} W/cm^2**

Table 2 Mean Sky Glow Radiance Measurements as a Function of Zenith Angle Kauai Site.

3.0 CONCLUSIONS

Chemical luminescence from excited hydroxyl radicals in the upper atmosphere at about 80 km provides a natural illumination source for night time imaging in the SWIR band between 1.0 and 1.7 µm. A series of image measurements have been made of sky glow radiation at two measurement sites, one outside of Albuquerque, and a second on the west coast of Kauai, Hawaii. The long term mean irradiance levels measured were consistent with published levels. Figure 3.1 shows figure 1.2 with data from tables 1 and 2 drawn in as horizontal lines.

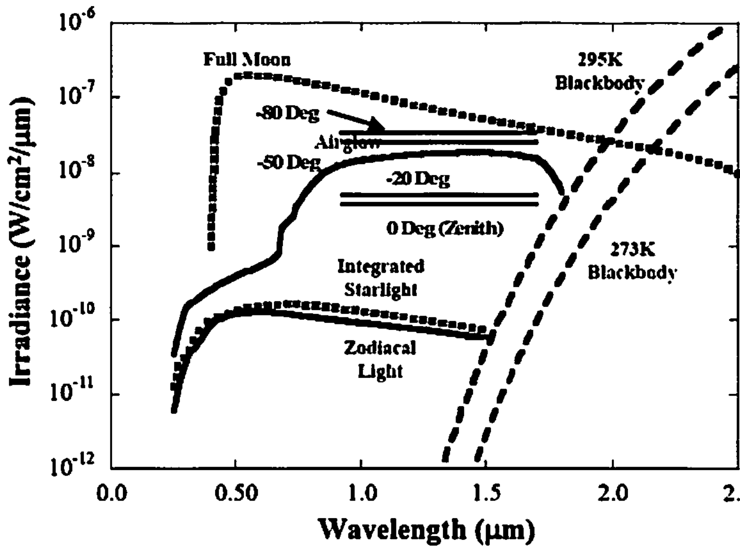


Figure 3.1 Night Time Illumination Sources With Sky Glow Measurements Superposed.

A series of measurements were taken of the sky glow at different elevation and azimuth angles. These measurements show significant short term and long term fluctuations in the sky glow irradiance.

REFERENCES

[1] Leinert, Bowyer, Haikala, et. al. "The 1997 Reference of diffuse night sky brightness", Aston. And Astrop. (Feb. 1997).

[2] Li, T., She, C., Williams, B., Yuan, T., "Concurrent OH imager and sodium temperature/Wind LIDAR observation of localized ripples over northern Colorado", Jrnl. Geo. Phys. Res., 110 1029-1034, (2005).

[3] Adler-Golden, S., "Kinetic parameters of OH nightglow modeling consistent with recent laboratory measurements", Spectal Science Inc. (1995).

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